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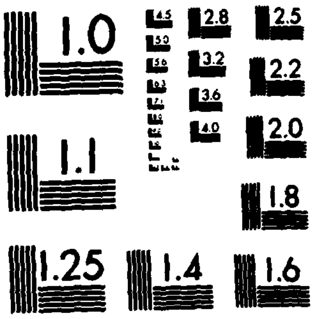

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The Hydrogen Coma of Comet Halley Before Perihelion: Preliminary Observations with Dynamics Explorer 1

by

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Abstract

alpha

The hydrogen coma of Comet Halley has been observed in resonantly scattered solar ~~Lyman-α~~ radiation during the period 1-29 January 1986 as the comet approached perihelion. These observations were obtained with the imaging photometer for vacuum-ultraviolet wavelengths on the spacecraft Dynamics Explorer 1. For the initial analysis of observations available in 17 orbits distributed throughout the period, least-squares fits are computed for the observed exponential decrease in brightness with radial distance from the nucleus. Brightness at the nucleus increased from (approx.) ~ 3 to 17 kR during the observing period. Preliminary analysis yields water production rates of $\sim 3.6 \times 10^{29}$ (10 to the 29th Power) and 1.9×10^{30} (10 to the 30th Power) molecules/sec on 1 and 29 January, respectively.

Introduction

Thermal heating of a comet's surface increases the sublimation rate substantially with decreasing heliocentric distances $\lesssim$ 5 AU, so that a well-developed, luminous coma of solar-illuminated gas and entrained dust is visible to terrestrial observers by ~ 3 AU [Wyckoff, 1982]. Unfortunately, the large outflow of gas and dust obscures from our direct view the surface and low-altitude atmosphere, and photodissociation rapidly modifies the atmospheric composition at altitudes $\lesssim 10^4$ km to create a secondary population of molecules and atoms. Spectroscopic analysis of emissions from this secondary population and its ionization products supports other evidence that the dominant constituent of a comet is water ice, with lesser quantities of the ices of methane, carbon dioxide and other molecules [Feldman, 1982]. It is the optical signatures of O, H and OH that provide indirect measures of the H_2O sublimation rate, with emissions in resonantly scattered sunlight from H at 121.6 nm and from the OH bands at about 308.5 nm that are the most intense [Feldman, 1982]. The hydrogen coma is observed to expand radially from the nucleus to distances of many millions of kilometers [e.g., Opal et al., 1974].

It is fortunate that the Earth-orbiting spacecraft Dynamics Explorer 1 (DE 1) remains an active, functioning spacecraft more than 54 months after launch, and that Comet Halley traversed the fields-of-view of the DE imaging photometers in an ~ 45-day period during its approach to perihelion. We have utilized this opportunity by scheduling imaging sequences during ~ 60 orbits throughout January 1986 for observations of the comet at the H Ly-α wavelength as its heliocentric distance decreased from ~ 1.0 to 0.63 AU. The results presented here are from an initial analysis of observations in 17 of these orbits.

Observations

For observations during January 1986 the minimum in column density of hydrogen between the comet and the spacecraft occurred in each orbit from about one hour before arrival at apogee to ~ 20 minutes afterwards. Six consecutive 12-minute images obtained within or near this optimum time interval for each of the 17 orbits have been processed and the images superposed to reduce statistical variations. For the observations of 4 January only five images are available to form a composite image. Using 4.7° x 4.7° comet-centered sections from 12 of the 17 composite images, a sequence of images is presented in Figure 1 which records the growth of the hydrogen coma with time as its heliocentric distance decreases from 1.0 to 0.63 AU. A false-color format is used in which a brightness of ~ 900 R (rayleighs) is coded reddish-blue and $\gtrsim$ 15 kR is white. No adjustments are made for the increasing geocentric distance to the comet, Δ, or for the decreasing heliocentric distance, r. The sun is located towards the upper left for each image, outside the photometer's field-of-view. For each frame in the figure the individual image pixels are replaced by a 5 x 5 array of color-monitor pixels and the magnified image array smoothed by a linear interpolation algorithm.

The more prominent VUV-bright stars near the comet are identified in the caption. The apparent angular dimensions of the stars in Figure 1 are representative of the angular resolution of the photometer with the exception that for stars brighter than the comet the apparent dimensions of the field-of-view are over emphasized. The apparent vertical elongation of some stars along the photometer's scan direction is due (1) to the fact that the angular dimension of the field-of-view and the overlap of adjacent pixels are greater along this direction and (2) to an ~ 1/8-pixel error level for alignment of the overlayed

Instrumentation

The DE-1 spacecraft carries three imaging photometers for investigations of Earth's aurora and geocorona at visible and vacuum-ultraviolet (VUV) wavelengths [e.g., Frank et al., 1985]. Initial perigee and apogee altitudes for the eccentric, polar orbit of DE 1 at launch on 3 August 1981 were ~ 570 km and 3.65 Earth radii. The orbital period is ~ 6.83 hours and the line of apsides advances at ~ 0.33°/day. In January 1986 the latitude of apogee was located over the South Pole. The fields-of-view of the three imaging photometers are aligned perpendicular to the spacecraft spin axis, and are separated by nearly equal azimuthal angles around the spin axis. The spacecraft spin axis is normally oriented perpendicular to the orbit plane at right ascension $\alpha = 250°$, declination $\delta = 0°$. A combination of a six-second spin period and the 0.125° motion of an internal mirror once per spin period allows each photometer to scan a 30° x 360° sector of the celestial sphere in 12 minutes. The 30° angular width of the scan region is centered on the spacecraft equatorial plane. Sufficient telemetry is provided to transmit in 12 minutes one 30° x 360° image from a single photometer or a 30° x 120° image from each of the three photometers. The selection of photometers, filters and image angles for each orbit is made weeks in advance, and the commands are stored in spacecraft memory daily for execution at the specified times. A detailed description of this instrumentation is provided by Frank et al. [1981].

scan lines. At 50% of peak response the field-of-view for a single pixel is nearly circular with a full angle of 17.4 arc min. At 10% of peak response, the effective full angles of the field-of-view along and normal to the scan direction are ~ 29 and ~ 20 arc min, respectively. Apparent elongation is greatest for stars positioned near the center of a scan line.

An estimate of the background Ly-α brightness due to exospheric and interplanetary hydrogen is made for each composite image by first identifying a comet-centered rectangular section in the composite image; dimensions of this array are 45 pixels along the scan direction and 25 pixels in the orthogonal direction (~ 10.6° x 6.5°). This rectangular array is further divided along the scan direction into three 15 x 25 pixel arrays. The upper and lower arrays are analyzed to determine a mean photometer background response in the absence of emissions from the comet. In the central array of 15 x 25 = 375 pixels the responses are due to Ly-α emissions from the comet and to background emissions which are assumed to be equal in brightness to background levels in the two adjacent sectors. Responses to the brighter VUV-bright stars are removed prior to calculating the background response. Contributions from weak stellar sources ($\lesssim$ 2-kR apparent brightness) not readily identified in the images are not eliminated for this preliminary analysis. For a composite image comprising six superposed images, the off-comet background arrays typically yield a total of 1905 counts in 4488 samples for an average background response of 0.42 ± 0.01 counts/pixel, or a brightness of ~ 650 ± 15 R.

Radial profiles of the cometary H Ly-α brightness are computed by first determining the approximate center of the emission region in a composite image. This position is estimated within an accuracy of ± 1/2 pixel by visual

inspection. For this initial analysis axial symmetry is then assumed about this point and the radial distance computed to the center of each pixel in the image. However, note that asymmetries can be observed, for example, in the images for 4, 6 and 16 January. The average response is determined for samples within concentric annuli about the center of the emission region, the background contribution subtracted, and H Ly-α brightness computed. The selection of an exponential function for least-squares fits to the brightness profiles is based on the radial dependence of the profiles observed here for a 17.4 arc min field-of-view. Three of these radial profiles are shown in Figure 2 for distances from the nucleus measured in Gm (10^6 km). The least-squares fit for a profile is computed using measurements at radial distances within which the brightness is greater than 300-700 R. This portion of the profile is identified by a solid line. An extrapolation to greater distances is identified by a dashed line. Probable errors in brightnesses due to statistical fluctuations in photometer responses and due to background subtractions are indicated by bars. An uncertainty of more than a factor of ten in a lower limit is denoted by an arrow. Intercepts of the radial profiles at the nucleus and scale heights for the exponential decreases with distance are plotted in Figures 3a and 3b, respectively, as a function of the heliocentric radial distance, r.

During the first 11 days of January the scale height increases from ~ 0.7 to ~ 1.4 Gm at an average rate of -3.5 ± 1.2 Gm/AU. A simple linear least-squares fit is used to identify the principal variations with r. This somewhat steady increase is interrupted after ~ 2100 UT on 11 January, and by ~ 2000 UT on 13 January the scale height has decreased to ~ 1.0 Gm.

Subsequently, the scale height increases at an average rate of $\sim 4.2 \pm 1.0$ Gm/AU, essentially identical to the rate before 12 January. During January the brightness increases at a rate for which a least-squares fit of the form r^{-n} yields an exponent of $n = 3.0 \pm 0.38$ (not shown). For least-squares fits to measurements before and after the change in scale height the exponents are $n = 3.0 \pm 1.9$ and 1.8 ± 0.5, respectively. Excluding the two measurements denoted by open circles, the exponent for the early period is $n = 4.1 \pm 0.7$. An analysis of all observations in the January period, when available, should allow us to determine if the exponent remains at $n \simeq 3$ throughout the month, or decreases after ~ 11 January from values initially in the range of 3 to 4 to later values of ~ 2. The mean diameter of the H Ly-α emission region at an extrapolated brightness of 300 R is given in Figure 3c.

The significant change in the hydrogen distribution after ~ 11 January follows by nearly two days a disconnection of the plasma tail [Brandt, 1982] which was initiated on 9 January (J. C. Brandt, private communication, 1986). Plasma tail disconnections appear to be associated with magnetic sector boundaries in the solar wind [e.g., Brandt, 1982], and the solar wind proton flux is frequently observed to increase in the several days following sector boundary crossings [Hundhausen, 1972]. Because charge exchange with solar wind protons is the dominant loss mechanism for cometary hydrogen, we conclude that the large decrease in scale height after 11 January may represent the indirect observation of an increase in the solar wind proton flux following a magnetic sector boundary crossing at the comet. Variations in brightness between consecutive orbits and over periods of several days may be related to rotation of the nucleus and enhanced activity observed at ~ 2.23-day intervals [Kaneda et al., 1986], and to variations in the solar Ly-α flux.

A direct comparison between these observations and the numerical model of Meier and Keller [1985] is facilitated by the convenient format of their presentation (see their Figure 10). The numerical values are obtained using the 'syndyname' model (see Meier and Keller [1985] and references therein) for a radially expanding hydrogen distribution from a point-source comet illuminated by the sun. The effects of multiple scattering are not considered. We present in Figure 2 the radial profiles for 1 and 28 January constructed from the revised Figure 10 of Meier and Keller (private communication, 1985) for their assumed line-center solar H Ly-α flux $f = 2 \times 10^{11}$ photons/cm^2-s-Å at 1 AU. Total water vapor production rates assumed by Meier and Keller for these two days are $Q(H_2O) = 1.6 \times 10^{29}$ and 4.8×10^{29} molecules/sec, respectively (reference model of the Interagency Consultative Group (IACG) Working Group on the Comet Halley Environment). The model production rate for 29 January is 5.2×10^{29} molecules/sec. The lifetime of hydrogen at $r = 1$ AU is taken to be 2×10^6 sec. The profiles for the sunward and antisunward projected radial directions on 28 January demonstrate the elongation in the H distributions which can be expected from radiation pressure effects. No significant difference is present for the two directions on 1 January. The Ly-α brightnesses calculated by Meier and Keller are less than the observed values by factors of ~ 2.3 (at ~ 1.5 Gm) and ~ 3.4 (at ~ 3 Gm), respectively, for 1 and 29 January. Combining the observations of 1 and 2 January to reduce the statistical errors lowers the difference from a factor of 2.3 to 2.0. It is assumed here that the greater observed Ly-α brightnesses are due to greater than expected water production rates. Note that the calculated radial dependence for the Ly-α brightness does not follow the observed exponential profile. Within the outer portion of the H distribution the shape of the model radial profile is sensitive to the assumed value for the H lifetime. Within the inner portion of the

coma the observed radial dependence may be influenced by the photometer's relatively wide field-of-view.

We estimate the water production rates for 1 and 29 January by scaling upwards the assumed rates of Meier and Keller. For a Ly-α brightness proportional to f and to the hydrogen production rate, these observations indicate that on 1 and 29 January $Q(H_2O) \approx 3.6 \times 10^{29}$ and 1.9×10^{30} molecules/sec, respectively. These estimates and estimates of instrument sensitivity for January assume $f = 1.8 \times 10^{11}$ photons/cm^2-s-Å. This value is obtained from measurements of the total solar Ly-α flux, F, with the Solar Mesospheric Explorer spacecraft ($F \approx 2.2 \times 10^{11}$ photons/cm^2-s) and the correlation with f given by Vidal-Madjar and Phissamay [1980].

The dominant error associated with these preliminary results is an uncertainty of a factor of 2 in the line-center Ly-α flux near solar minimum relative to the total flux [see Vidal-Madjar and Phissamay, 1980]. Uncertainty in instrument sensitivity for January 1986 is $\lesssim$ 50% for this preliminary analysis, and corrections not applied here for the finite field-of-view of the photometer will increase the brightnesses by at least 30% at the nucleus. Uncertainties in the model calculations of Meier and Keller and normalizations to the observations will correspondingly vary the computed water production rates.

Acknowledgements

The timely distribution of SME solar Lyman-α flux measurements by Dr. C. A. Barth and his colleagues at the University of Colorado's Laboratory for Atmospheric and Space Physics is gratefully acknowledged. This research was supported in part by NASA under grants NAG5-483 and NGL-16-001-002 and by ONR under grant N00014-85-K-0404.

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Figure Captions

Figure 1. A sequence of twelve 4.7° x 4.7° comet-centered images of Comet Halley at the Ly-α wavelength of atomic hydrogen. The images were obtained from 1 through 29 January 1986 as the geocentric distance (Δ) increased from 1.15 to 1.55 AU and the heliocentric distance (r) decreased from 1.00 to 0.63 AU. Four VUV-bright stars are readily identified in this sequence: γ Aquarii on 1 January; ο Aquarii on 4, 6, 9 and 11 January; and the weaker pair HD207888 (left) and HD208176 (right) on 9, 11 and 13 January. Apparent motion of the stars is approximately from left to right.

Figure 2. Comparisons of radial profiles of observed H Ly-α brightness as a function of distance from the comet nucleus for observations on 1, 13 and 29 January 1986 with the model profiles by Meier and Keller [1985] for 1 and 28 January.

Figure 3. (a) Brightness of H Ly-α emissions at the nucleus as a function of heliocentric distance. (b) Scale height for exponential decrease in H Ly-α brightness with distance from the nucleus. (c) Diameter of the hydrogen coma corresponding to an extrapolated H Ly-α brightness of 300 R.

HYDROGEN COMA OF COMET HALLEY 1-29 JANUARY 1986
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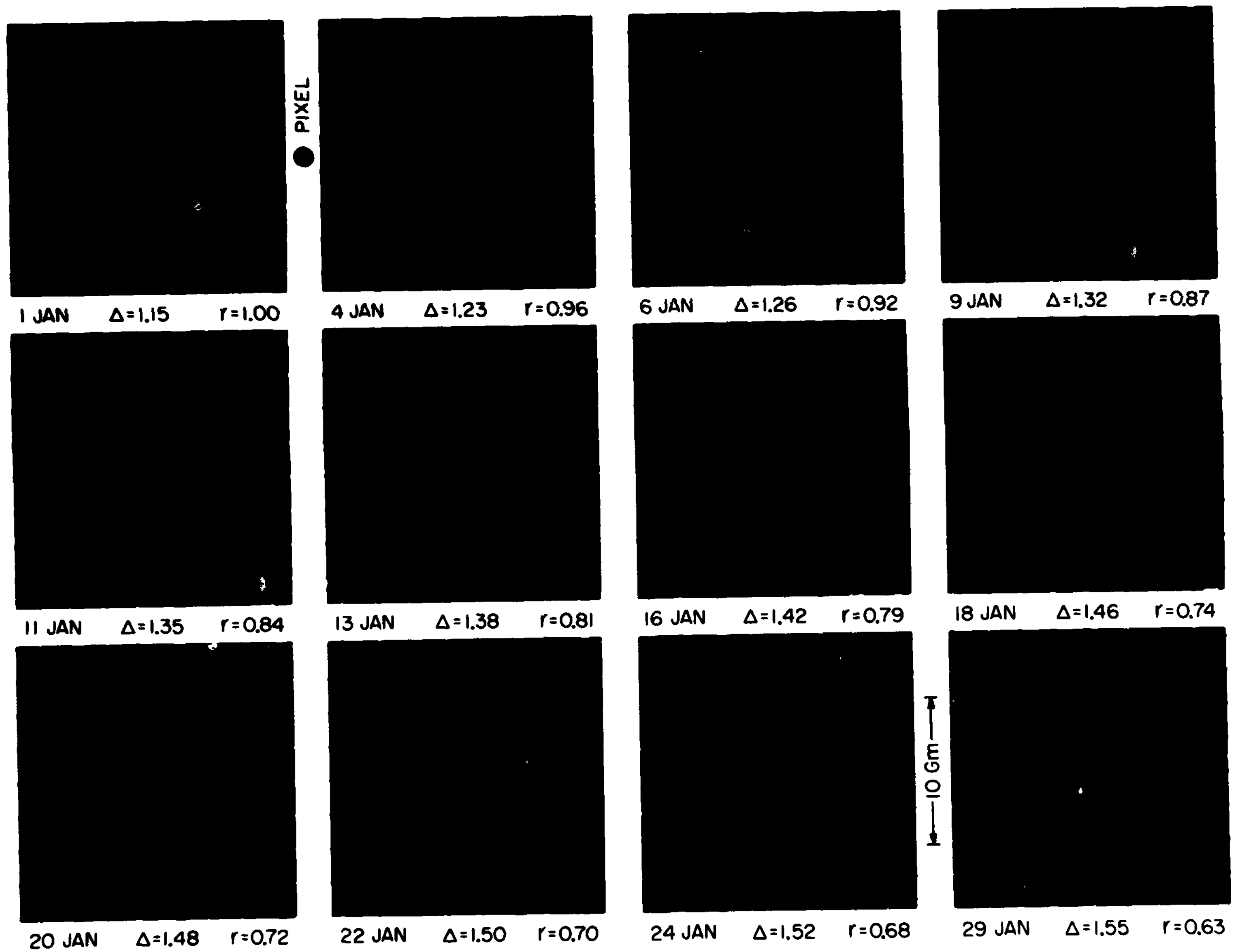
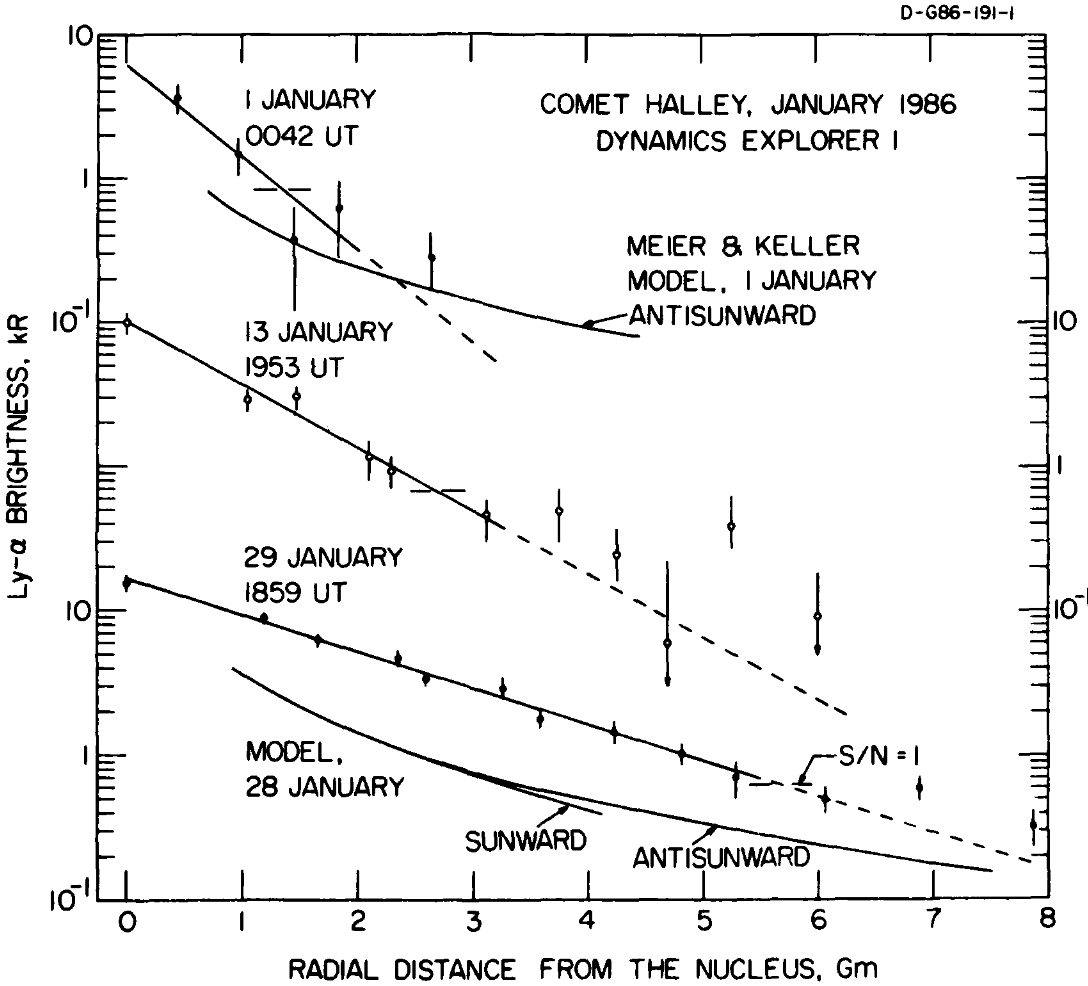


Figure 1



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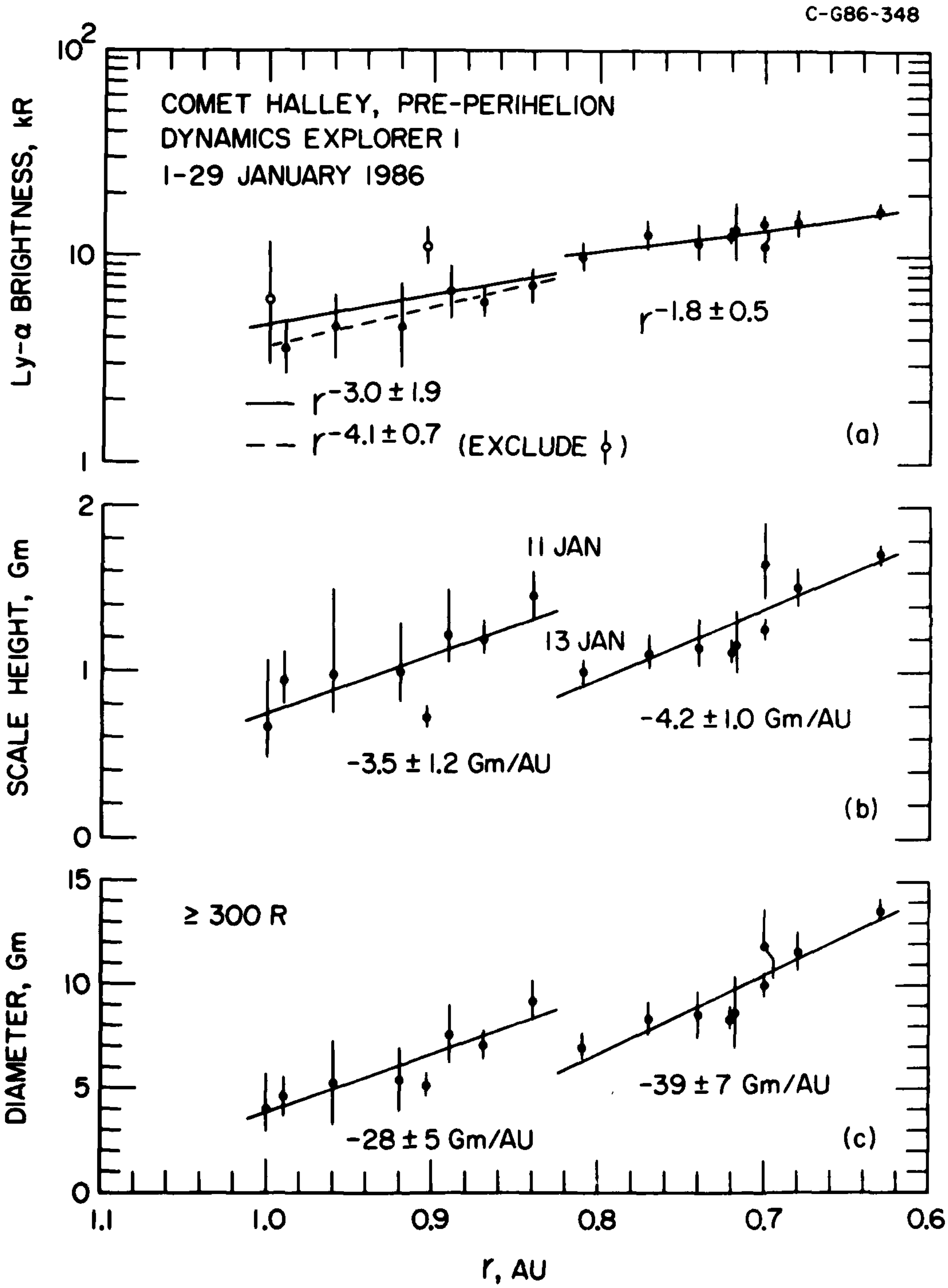
Ly-α BRIGHTNESS, kR
RADIAL DISTANCE FROM THE NUCLEUS, Gm

Figure 2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COMET HALLEY, PRE-PERIHELION
DYNAMICS EXPLORER I
1-29 JANUARY 1986
Ly-α BRIGHTNESS, kR
$r^{-1.8 \pm 0.5}$
$r^{-3.0 \pm 1.9}$
$r^{-4.1 \pm 0.7}$ (EXCLUDE)
(a)
SCALE HEIGHT, Gm
11 JAN
13 JAN
-4.2 ± 1.0 Gm/AU
-3.5 ± 1.2 Gm/AU
(b)
DIAMETER, Gm
≥ 300 R
-39 ± 7 Gm/AU
-28 ± 5 Gm/AU
(c)
r, AU

Figure 3

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